

**Claims:**

What is claimed is:

1. A time synchronization apparatus for synchronizing operation of a first controller with that of a second controller in a control system, the synchronization apparatus comprising:
  - a processor interface for interfacing the synchronization apparatus with a host processor;
  - a transmitter adapted to transmit synchronization information and data to a network in the control system;
  - a receiver adapted to receive synchronization information and data from the network; and
  - a timing system with a clock and maintaining an indication of time according to information received from one of the network and the host processor.
2. The time synchronization apparatus of claim 1, being configurable to operate as one of a synchronization master and a synchronization slave.
3. The time synchronization apparatus of claim 1, being configured to operate as a synchronization master, wherein the transmitter periodically transmits message frames at a fixed period.
4. The time synchronization apparatus of claim 3, wherein the fixed period is about 50 $\mu$ s.
5. The time synchronization apparatus of claim 3, wherein the transmitter transmits a message frame having an LCM indicator at a least common multiple (LCM) interval.
6. The time synchronization apparatus of claim 5, wherein the LCM interval is 600ms.

7. The time synchronization apparatus of claim 3, being configured as a synchronization master, wherein the transmitter transmits message frames having multiplexed data and direct data.

8. The time synchronization apparatus of claim 7, wherein the frame comprises three flag bytes, a control byte, a data field comprising the multiplexed data and the direct data, and two CRC bytes.

9. The time synchronization apparatus of claim 8, wherein the data field comprises 6 32 bit words, and wherein the amount of multiplexed data and the amount of direct data in each message frame is configurable.

10. The time synchronization apparatus of claim 9, wherein each message frame comprises a direct data portion and a multiplexed data portion, wherein the direct data comprises the direct data portion of a single frame, and wherein the multiplexed data comprises the multiplexed data portions of a plurality of frames.

11. The time synchronization apparatus of claim 10, wherein the multiplexed data portion comprises configuration information indicative of the amount of multiplexed data and the amount of direct data in each message frame.

12. The time synchronization apparatus of claim 9, wherein the amount of multiplexed data and the amount of direct data in each message frame is configurable according to information from the host processor.

13. The time synchronization apparatus of claim 7, wherein the timing system is adjustable according to information received from the host processor.

14. The time synchronization apparatus of claim 1, being configured as a synchronization slave, wherein the receiver receives message frames at a fixed period, and wherein the timing system is adjusted according to the fixed period.

15. The time synchronization apparatus of claim 14, wherein the fixed period is about 50 $\mu$ s.

16. The time synchronization apparatus of claim 14, wherein the receiver receives a message frame having an LCM indicator at a least common multiple (LCM) interval.

17. The time synchronization apparatus of claim 16, wherein the LCM interval is 600ms.

18. The time synchronization apparatus of claim 16, wherein the timing system is adjusted according to the LCM indicator.

19. The time synchronization apparatus of claim 16, wherein the receiver interrupts the host processor according to the LCM indicator.

20. The time synchronization apparatus of claim 14, wherein the transmitter transmits message frames at the fixed period.

21. The time synchronization apparatus of claim 20, wherein the message frames received and transmitted by the receiver and transmitter, respectively, comprise multiplexed data and direct data.

22. The time synchronization apparatus of claim 21, wherein the message frames comprise a data field with 6 32 bit words, and wherein the amount of multiplexed data and the amount of direct data in each message frame is configurable.

23. The time synchronization apparatus of claim 22, wherein each message frame comprises a direct data portion and a multiplexed data portion, wherein the direct data comprises the direct data portion of a single frame, and wherein the multiplexed data comprises the multiplexed data portions of a plurality of frames.

24. The time synchronization apparatus of claim 23, wherein the multiplexed data portion comprises configuration information indicative of the amount of multiplexed data and the amount of direct data in each message frame.

25. The time synchronization apparatus of claim 24, wherein the receiver presents direct data from received message frames to the host processor at the fixed period.

26. The time synchronization apparatus of claim 25, wherein the receiver presents multiplexed data from received message frames to the host processor at a multiple of the fixed period.

27. The time synchronization apparatus of claim 14, comprising a multiplier receiving an operand from the receiver, a multiplication value from the host processor, and providing a multiplication result value to at least one of the host processor and the transmitter, wherein the multiplication result value is the product of the multiplication value and the operand.

28. The time synchronization apparatus of claim 27, wherein the direct data received in the message frame comprises the operand.

29. The time synchronization apparatus of claim 14, wherein the message frame comprises a status component indicative of the status of an upstream device, wherein the receiver provides the status component to the host processor.

30. The time synchronization apparatus of claim 14, wherein the transmitter transmits message frames at the fixed period comprising direct data and multiplexed data.

31. The time synchronization apparatus of claim 30, wherein at least a portion of the direct data in the message frames transmitted by the transmitter is provided to the transmitter by the receiver, wherein the direct data from a received message frame is passed through to the transmitter.

32. The time synchronization apparatus of claim 30, comprising a multiplier, wherein at least a portion of the direct data in the message frames transmitted by the transmitter comprises a multiplication result value provided to the transmitter by the multiplier.

33. The time synchronization apparatus of claim 30, wherein at least a portion of the direct data in the message frames transmitted by the transmitter is provided to the transmitter by the host processor.

34. The time synchronization apparatus of claim 33, wherein the multiplexed data in the message frames transmitted by the transmitter is provided to the transmitter by the host processor.

35. The time synchronization apparatus of claim 1, being configured as an intermediate node in a daisy-chain topology, the receiver receiving synchronization information from an upstream device in the daisy-chain, and the transmitter transmitting the synchronization information to at least one downstream device in the daisy-chain.

36. The time synchronization apparatus of claim 35, wherein the receiver receives message frames at a fixed period, and wherein the transmitter transmits message frames at the fixed period comprising direct data and multiplexed data.

37 The time synchronization apparatus of claim 36, wherein at least a portion of the direct data in the message frames transmitted by the transmitter is provided to the transmitter by the receiver, wherein the direct data from a received message frame is passed through to the transmitter.

38. A synchronization module in a control chassis for synchronizing operation of a first controller in the control chassis with that of a second controller outside the control chassis, comprising:

a host processor in communication with the first controller via a backplane bus in the control chassis;

a transmitter adapted to transmit synchronization information and data to a network in the control system;

a receiver adapted to receive synchronization information and data from the network;

a timing system with a clock and maintaining an indication of time according to information received from one of the network and the host processor; and

a synchronization circuit operatively associated with the host processor, the transmitter, the receiver, and the timing system, and configurable by the host processor to operate the module as one of a synchronization master and a synchronization slave.

39. A synchronization circuit for synchronizing operation of a first controller with that of a second controller in a control system, comprising:

a processor interface for interfacing the synchronization circuit with a host processor;

a transmitter component adapted to transmit synchronization information and data to a network in the control system;

a receiver component adapted to receive synchronization information and data from the network; and

a timing system with a clock and maintaining an indication of time according to information received from one of the network and the host processor,

wherein the synchronization circuit is configurable by the host processor to operate as one of a synchronization master and a synchronization slave.

40. The system of claim 39, wherein the transmitter component periodically transmits message frames comprising direct data, and wherein the direct data is obtained from at least one of the receiver component and the host processor.

41. The system of claim 39, further comprising a multiplier, wherein the transmitter component periodically transmits message frames comprising direct data, and wherein the direct data is obtained from at least one of the receiver, the host processor, and the multiplier.

42. The system of claim 39, wherein the transmitter component periodically transmits message frames comprising multiplexed data, and wherein the multiplexed data is obtained from the host processor.

43. The system of claim 39, wherein the transmitter component periodically transmits message frames comprising direct data and multiplexed data, and wherein the amount of the multiplexed data in the message frames and the amount of direct data in the message frames is configurable.

44. The system of claim 39, wherein the receiver component periodically receives message frames comprising direct data, multiplexed data, and status information from the network, and wherein the synchronization circuit provides at least one of received direct data, received multiplexed data, and received status information from the receiver component to the host processor.

45. The system of claim 44, further comprising a multiplier operating on the received direct data, and wherein the synchronization circuit provides a multiplier result value from the multiplier to the host processor.

46. The system of claim 45, wherein the synchronization circuit provides a multiplication value to the multiplier from the host processor.

47. The system of claim 44, wherein the status information comprises at least one of status of an upstream device, and an error counter.

48. The system of claim 39, wherein the transmitter component periodically transmits message frames comprising direct data, multiplexed data, and configuration information, and wherein the synchronization circuit provides at least one of the direct data, multiplexed data, and configuration information to the transmitter component from the host processor.

49. The system of claim 39, wherein the transmitter component periodically transmits message frames having synchronization information, wherein the synchronization information is obtained from the timing system, and wherein the timing system is adjusted according to at least one of synchronization information received from the network and synchronization information from the host processor.

50. The system of claim 39, wherein the synchronization circuit interrupts the host processor according to receipt of an LCM indicator by the receiver.

51. The system of claim 39, wherein the synchronization circuit interrupts the host processor periodically for presentation of at least one of direct data and multiplexed data from the receiver to the host processor.

52. A synchronization system for synchronizing a first controller with a second controller in a control system, comprising:  
 means for interfacing the synchronization circuit with a host processor;  
 means for transmitting synchronization information and data to a network in the control system;  
 means for receiving synchronization information and data from the network; and



means for maintaining an indication of time according to information received from one of the network and the host processor, wherein the synchronization circuit is configurable by the host processor to operate as one of a synchronization master and a synchronization slave.